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The variation of absorption coefficient of absorber modules with ambient conditions

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THE VARIATION OF ABSORPTION COEFFICIENT OF ABSORBER MODULES WITH AMBIENT CONDITIONS

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Summary

The absorption coefficient of a given absorber is shown not to be a unique quantity, but to depend on a number of factors. These include the size of room in which it is located, as well as the proximity of other absorbers and of diffusing obstacles. The magnitude of these effects and the frequency range over which they are significant has been examined experimentally, so that steps can be taken to reduce the uncertainty of prediction of acoustic treatment of concert halls and large music studios; substantial savings in the overall cost of treatment would result. A suggestion is made to account for the effect of the module size on the absorption coefficient, and of the ratio of area of room surfaces to area of absorbent.

Issued under the authority of

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Section Title Page

Summary .... Title Page

1. Introduction 1

2. Construction of absorber modules 1

3. Measurements 1

3.1. Measurements using model absorbers 1
  3.1.1. Wide-band absorbers 1
  3.1.2. Narrow-band absorbers 3
  3.1.3. Discussion of results 3
3.2. Measurements using full-size absorbers 3
  3.2.1. Wide-band absorbers 4
  3.2.2. Narrow-band absorbers 4
  3.2.3. Discussion of results 4

4. Conclusions 8

5. References 8

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1. Introduction

During some experiments to determine the construction of scaled absorber modules for use in the model of a large music studio,[1,2] use was made of a model reverberation room[3] made to scaled ISO standards.[4] The absorption coefficients, particularly those at scaled mid-band and low frequencies did not always vary with the materials used in the manner expected and the predictions of reverberation time of the model (based on the ISO model reverberation room measurements) were substantially in error.

The adopted solution was to measure the absorbent properties of the modules in the model studio itself, the volume of the latter being equivalent to about 8100 m^3, i.e. over 40 times greater than that of an ISO reverberation room. Under these conditions the absorption coefficients* at mid-band and low frequencies were considerably greater than those calculated from the reverberation room measurements by factors of up to three.

A further complication was that the absorption coefficient of wide-band modules varied at the mid-band and low frequencies by factors of up to three according to whether they were mounted on the coffered ceiling, between the diffusing ribs on the walls, or on the plane floor[1,2] of the model studio. These variations were greatest in the frequency region in which the sufface irregularities might be expected to have the least diffusing effect (i.e. low frequencies) and were negligible in the higher frequency region where their effect might well be expected to be greatest. Furthermore it was shown that even for a given method of mounting in the model studio, the absorption coefficient per module varied appreciably with the number of modules present. In all it was found to be almost impossible from model reverberation room measurements to deduce accurately the number of absorber modules necessary for a given reverberation time in the model studio.

The standard method laid down by the ISO for the measurements of absorbers is to use one single absorbing area of 10 m^2 on the floor. In studios, absorbers are never used in this manner, but are scattered over the walls and ceiling to improve diffusion and to reduce the likelihood of flutter echoes. It is well known[5] that the absorbing power of a number of small separate absorbers is greater than that of the same absorbers gathered into one large area and this is generally attributed to the greater boundary length in the former case. Even from this aspect, therefore, the ISO recommended method gives results which are by no means accurately applicable to standard studio conditions.

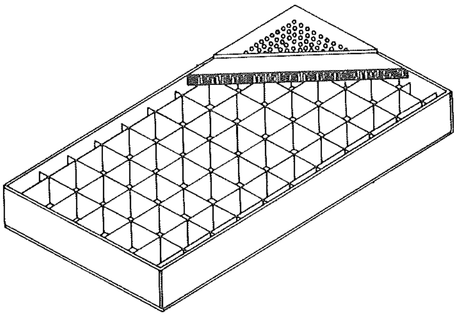

Fig. 1 - Construction of full size modular absorber

This Report gives details of an investigation into some of the effects of various methods of measurement on the apparent absorption coefficient of modular absorbers, and in particular, the effect of the volume of the environment.

2. Construction of absorber modules

The construction of a typical absorber module is illustrated in Fig. 1. An otherwise air-tight box is faced with a perforated material, whose percentage open-to-closed ratio is chosen according to the frequency range to be covered. A wide-band absorber would have an open-to-closed ratio of approximately 20% whereas one designed for low frequencies only might have a ratio of 0·5%. Behind the perforated front is an absorbing layer whose flow resistance is also chosen according to the frequency range to be covered, being small for low frequency absorbers. This layer is supported by a honeycomb partition which subdivides the enclosed air space into small sections, thus inhibiting transverse air waves; it also prevents physical movement of the absorber at low frequencies where its mechanical reactance is low. Finally, the depth of the module is also chosen according to its operative frequency range, low frequency absorbers being relatively deep. Typical values are 190 mm deep for wide-band absorbers and 300 mm deep for bass absorbers.

3. Measurements

3.1. Measurements using model absorbers

This Section gives, in detail, the measurements made in the model ISO room and in the model studio which were referred to in Section 1.

3.1.1. Wide-band absorbers

The variation in absorption coefficient with frequency of the wide-band modular absorbers as measured

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* Note: Eyring's formula for sound absorption coefficient was used throughout.

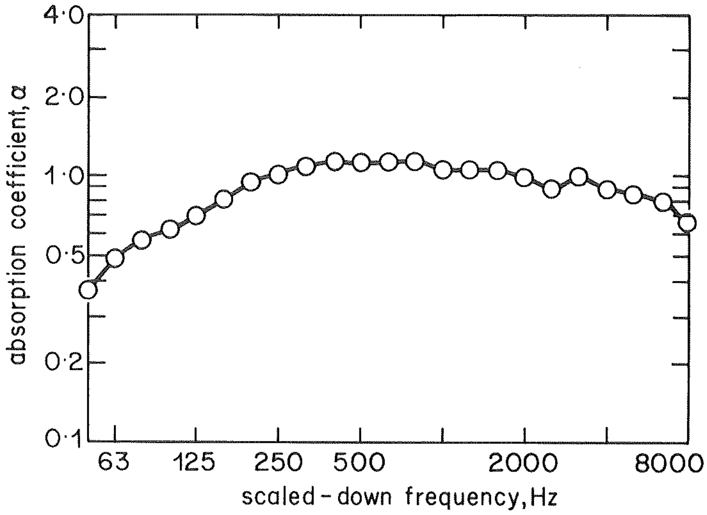


Fig. 2 - Absorption coefficient of model wide band absorber as measured in model ISO room

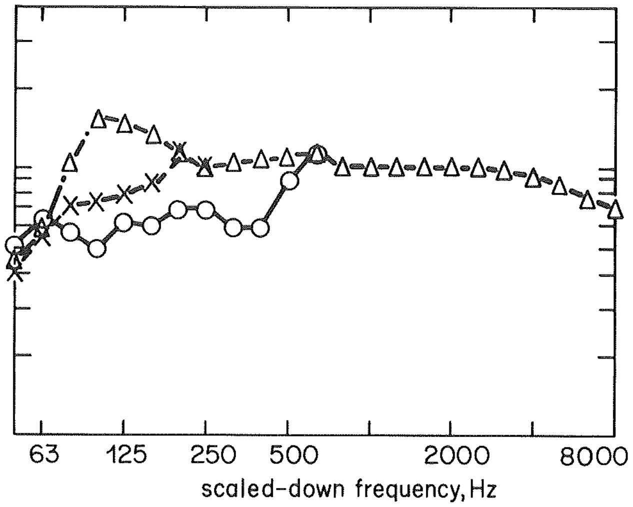


Fig. 3 - Absorption coefficient of model wide band absorber as measured in Model Studio

O——O (*a*) Modules mounted on ceiling
X — — X (*b*) Modules mounted on walls
Δ—— • Δ (*c*) Modules mounted on floor

in the model ISO reverberation room is given in Fig. 2. The results are similar to those expected on the basis of full-size modules except that below the equivalent of about 200 Hz, the absorption coefficient is rather low. The results of measurements made in the model studio with the same modules are shown in Fig. 3, for three mounting conditions:

(a) On the ceiling
(b) On the walls, and
(c) On the floor.

The ceiling had coffering the equivalent of 610 mm (24") deep and there were irregularly spaced diffusing ribs on the walls the equivalent of 305 mm (12") deep. Fig. 4 gives a view of the model with absorbers in situ and Fig. 5 shows the variation of the apparent absorption coefficient of the wide-band modules with the number of absorbers present, the absorbers being distributed evenly over the four walls and the ceiling. For the condition when only 55 absorbers were present, the accuracy unavoidably is poor and the curve is irregular. However, the general trend is obvious.

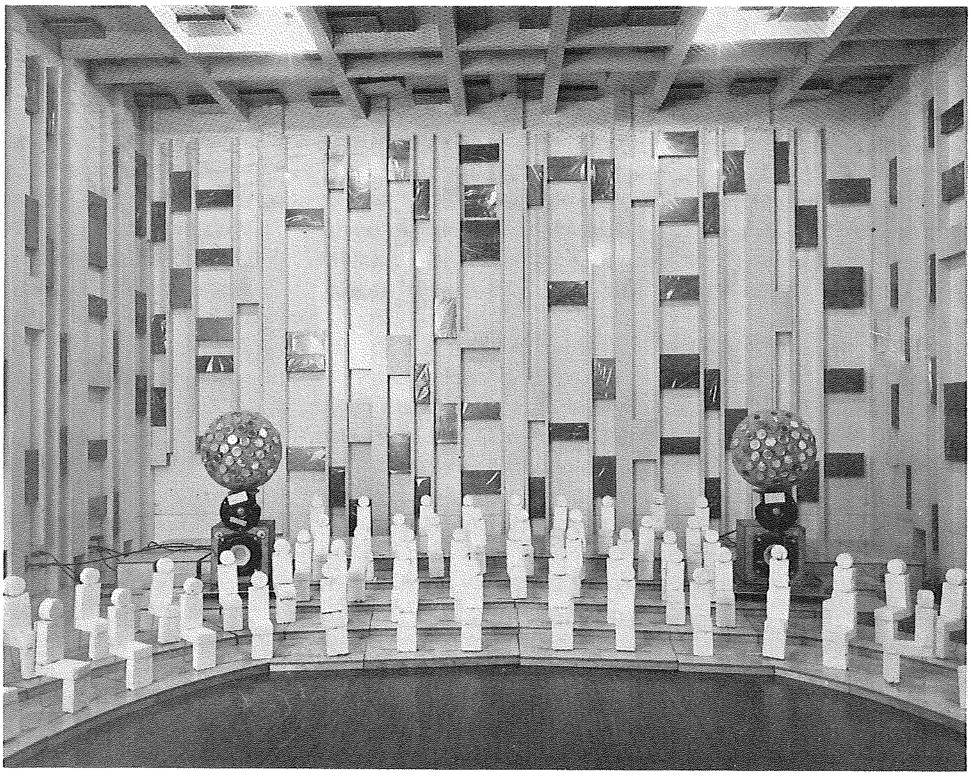


Fig. 4 - View of Model Studio, showing absorbers and diffusing elements

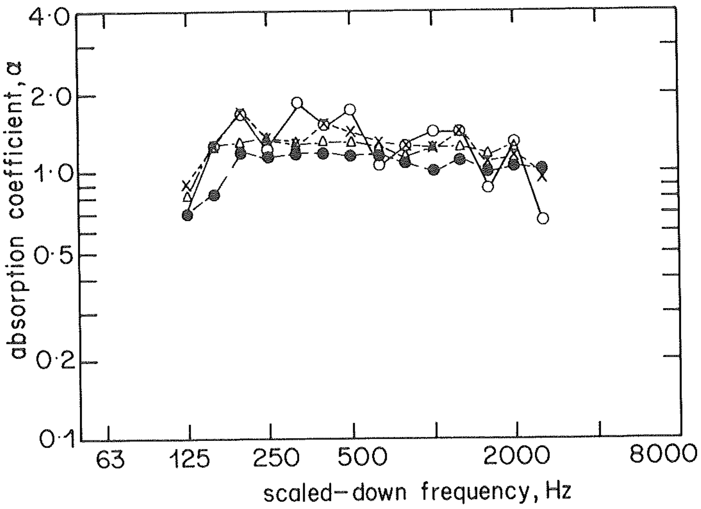


Fig. 5 - Variation of absorption coefficients of model wide band absorbers with number of absorbers present; measured in Model Studio

○——○ 55 Absorbers x------x 112 Absorbers
△—·—·△ 225 Absorbers ●——● 450 Absorbers

3.1.2. Narrow-band absorbers

Since the wide-band absorbers were relatively ineffective below 200 Hz, narrow-band modules were designed to extend the range downwards in frequency; these by their nature are more highly absorbing at their peak value. The results of measurements of the variation of absorption coefficient with frequency in the model ISO reverberation room are given in Fig. 6 for two conditions, together with the results of measurements of the same modules taken in the model studio.

3.1.3. Discussion of results

It is evident that there is a very large variation in the values of absorption coefficient of the same modules in the different conditions, but the factors responsible are by no means clear. The use of a large measurement room would be expected to increase the degree of diffusion present and thereby to improve the accuracy of measurement, although the ISO room is generally regarded as accurate down to 125 Hz. On the other hand, the effect of the diffusing irregularities in the model studio seem to be greatest at the wavelengths where their effect would be expected to be least. It is just possible that above 630 Hz the diffusion in such a large room is already almost perfect and that it is only below this frequency that improvements are perceptible. However, the values of absorption obtained are least in the conditions where the local disturbance to sound waves is greatest, i.e. on the ceiling, and are greatest on the plane floor (refer to Fig. 3).

3.2. Measurements using full-size absorbers

In view of the fact that these variations would lead to very expensive errors in studio treatment, it was decided to investigate the effect of the size of the reverberation room on the measured absorption coefficients. Three different sized rooms were available for this experiment; one at BBC Research Department, Kingswood Warren (KW), measured approximately 7·0 m x 5·0 m x 3·0 m giving a volume of 106 m^3, i.e. about half the ISO recommended volume, one much taller measuring about 6·0 m x 5·4 m x 6·1 m at the British Plaster Board (BPB) Laboratories giving a volume of 200 m^3 and thus to ISO standards, and a third measuring about 14·0 m x 9·2 m x 9·8 m at the Building Research Station (BRS), Garston, giving a volume of 1300 m^3, well beyond the ISO standard, but still only 1/6th the volume of the full size studio which had been modelled.

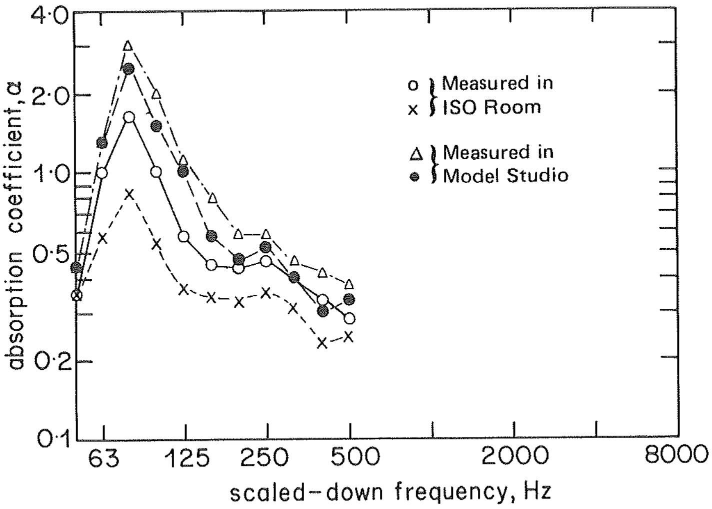


Fig. 6 - Absorption coefficient of model narrow band absorbers as measured under differing conditions

○——○ △—·—·△ Random spacing
●— —● x-----x Groups of three

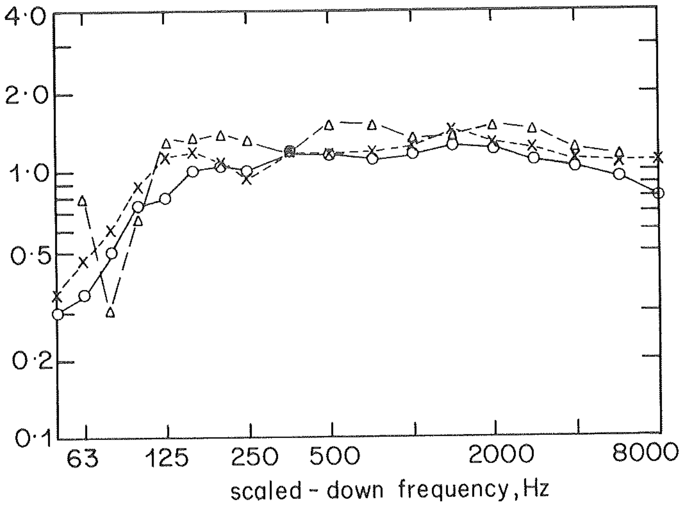


Fig. 7 - Absorption coefficient of full size wide band absorbers randomly spaced as measured in small, standard and large reverberation rooms

○——○ KW x----x BPB (ISO)
△——△ BRS

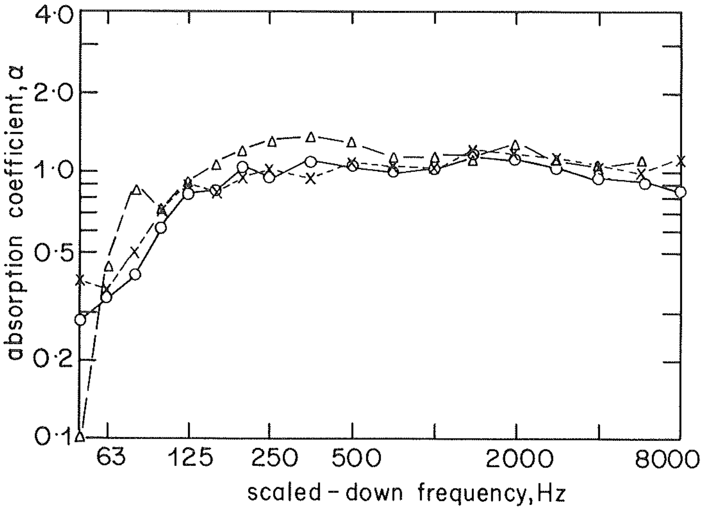


Fig. 8 - Absorption coefficient of full size wide band absorbers in groups of three as measured in small, standard and large reverberation rooms

O———O KW   X- - - - -X BPB (ISO)

Δ— —Δ BRS

3.2.1. Wide-band absorbers

Curves showing the results of measurements of wide-band absorbers in each of the three reverberation rooms are shown in Figs. 7 and 8; curves are given both for random spacing of individual modules and for groups of three modules respectively. In all cases, the modules were placed on the floor.

3.2.2. Narrow-band absorbers

Curves showing the results of measurements of narrow-band bass absorbers in each of the three reverberation rooms are shown in Figs. 9 and 10 both for random spacing of individual modules and for groups of three.

In the measurement of these modules a further complication arises due to the extreme efficiency of absorption at resonance. If 1/3rd octave band noise or 10% warble tone is used for the measurement and the sound-decay is analysed through octave band filters the decay curve (sound pressure level in dB's against time) is concave at the resonant frequency. This is due to the rapid absorption of sound at the peak frequency followed by slower absorption at frequencies off resonance. Analysis of the decay through 1/3rd octave band filters reduces this effect considerably although the decay curve is still slightly concave. Warble tone gives slightly different results from 1/3rd octave noise owing to the finite spacing of the side bands. The difference in results is illustrated in Fig. 11. Thus, in the remainder of the figures in this Report, the slope of the early portion of the decay, providing the range was not less than 25 dB, was taken as representative of the peak absorption.

3.2.3. Discussion of results

1. Variation in bass absorption with size of room

It is evident from the curves that there is a quite large variation in absorption at bass frequencies, depending largely on the size of the reverberation room. What is, perhaps, surprising is the magnitude of the variation and the frequency up to which it extends, i.e. well above the nominal 125 Hz, down to which the ISO room has usually been considered to be accurate. It appears therefore, that if absorption figures obtained in an ISO room are used in calculations for a concert hall or a large studio they may effectively be in error at low frequencies by 2:1. As the bass absorbers are the largest and most expensive

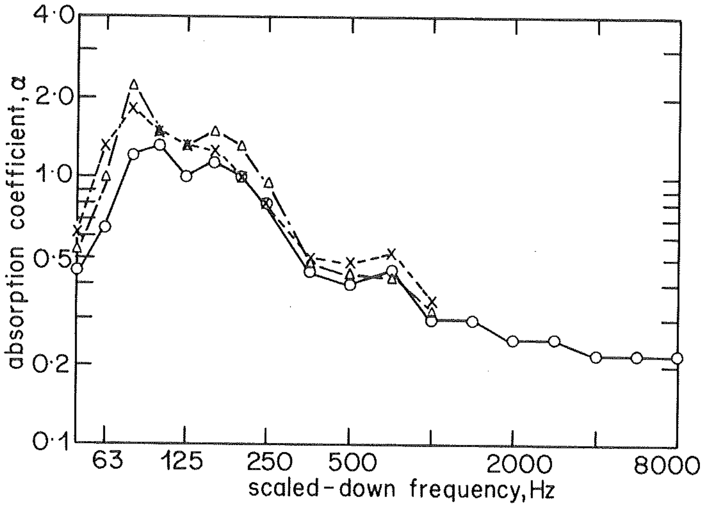


Fig. 9 - Absorption coefficient of full size narrow band absorbers randomly spaced as measured in small, standard and large reverberation rooms

O———O KW   X- - - - -X BPB (ISO)

Δ—·—·—Δ BRS

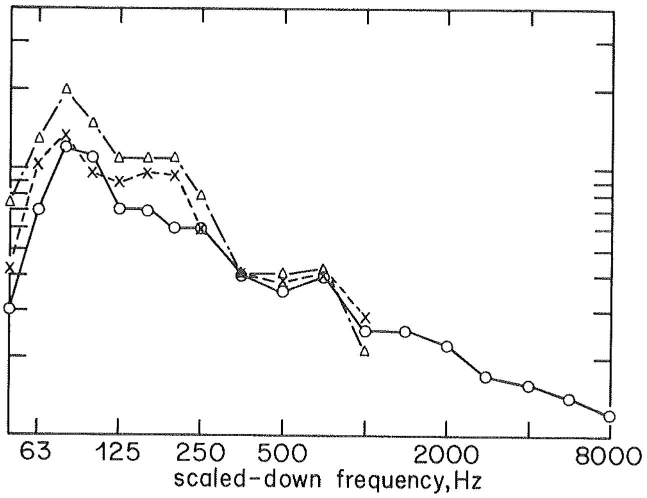


Fig. 10 - Absorption coefficient of full size narrow band absorbers in groups of three as measured in small, standard and large reverberation rooms

O———O KW   X- - - - -X BPB (ISO)

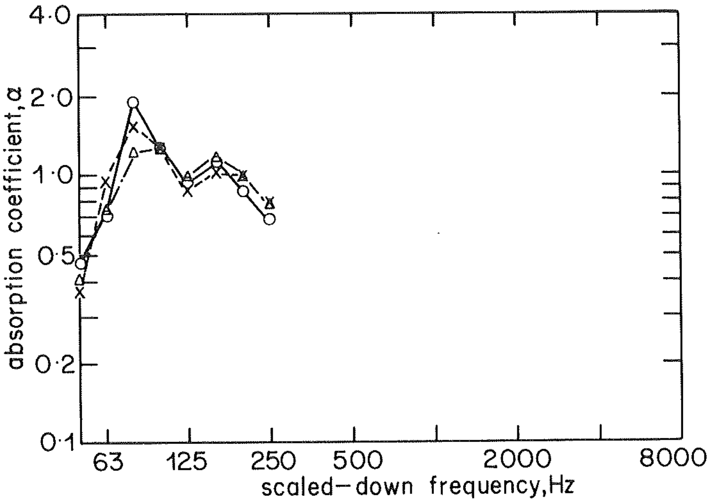
Δ—·—·—Δ BRS

Fig. 11 - Absorption coefficient of full size narrow band absorbers randomly spaced as measured in room at BRS using 1/3rd octave bands of noise and warble tone

o———o Excitation 1/3 octave noise. Analysis through 1/3 octave filters.

x– – – – x Excitation 1/3 octave noise. Analysis through octave filters.

Δ——·——Δ Excitation 10% warble tone. Analysis through octave filters.



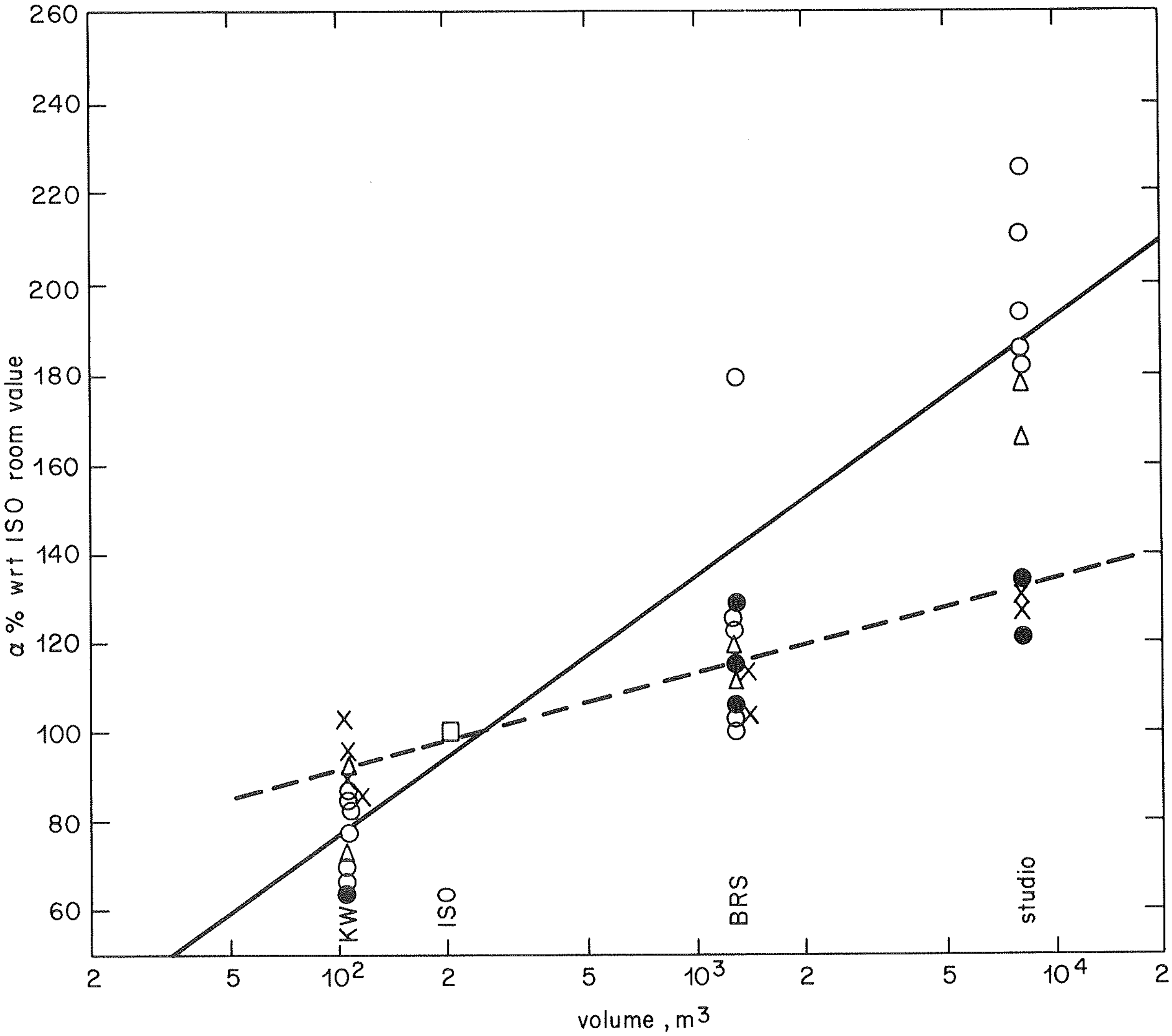


Fig. 12 - Relation between volume of measuring room and absorption coefficient at bass

80 Hz, 100 Hz, 125 Hz } O
160 Hz Δ
200 Hz ●
400 Hz X
——— 80 – 160 Hz
– – – – 200 – 400 Hz

part of the acoustic treatment, this error will be costly in materials, and in labour, both on installation and on subsequent modification.

It is of interest to plot the variations in absorption coefficient against the volume of the measurement room taking those obtained in the ISO room or model ISO room as a standard. This has been done in Fig. 12 for randomly spaced absorbers and for frequencies from 80 Hz to 400 Hz where the normalised absorption coefficient is plotted against the logarithm of the volume. It will be seen that whilst there is an appreciable spread in the points plotted, even for a given frequency, nevertheless for frequencies from 80 Hz to 160 Hz inclusive there is a strong general trend towards higher absorption for higher room volume (linear regression analysis used). It may well be significant that the results from the BRS room were obtained from tests employing warble tone, those from the ISO room only partially so and the remainder from 1/3rd octave noise using 1/3rd octave filters. The difference, shown in Fig. 11, according to method of measurement, may well account for the fact that the results from the BRS room tend to be low. It is clear from the results that the absorption coefficient at the bass in large rooms may reach values well over twice those predicted from an ISO room. For the largest volume even the lowest value plotted for this frequency (80 to 160 Hz) range is 1·65 times the ISO room value.

The points for 200 Hz are obviously much lower for the largest volume used and average about 1·25 times the ISO room value, whilst those for 400 Hz suggest that even the smallest room may give fairly accurate values. It may be noted that the corresponding points for 160 Hz are slightly lower than the main group for the largest volume, but the meagreness of the data does not justify a separate curve. Such a division would, however, be expected in view of the trend for the 200 Hz and 400 Hz points.

2. Variation in absorption with size of sample absorber patches

A further point to note is the large difference in absorption coefficient between individual absorbers scattered randomly and those in groups of three. Fig. 6 shows the most conspicuous example, but other figures also show the effect.

The increased absorption obtained on subdividing a large sample of absorbent material has been known for some time. It is usually attributed to the effects of increasing the length of the sample perimeter and is termed the edge effect. Various attempts[5,6,7,8] have been made to explain this phenomenon, but the results to date have not been very satisfactory. For example, Daniel[7] derives a formula which states that the effective absorption coefficient of a sample is

$$\alpha = \alpha_{\infty}(1 + \eta/kb)$$

where α_{∞} is the absorption coefficient for a sample of infinite area, η is a function of the acoustic admittance, k is $2\pi/\lambda$, b is the length of one side of the equivalent square sample, and λ is the sound wavelength.

This formula is open to the objection that whatever the value of the admittance, then for samples which are very small compared with the wavelength, the effective absorption coefficient must be very large indeed, and continue to increase with further subdivision. This is obviously wrong.

An explanation can be suggested which should hold for values of absorber dimensions which are small compared with the wavelength. If the absorber is considered to be a rigid piston radiator, it is well known that the directional properties will depend directly on its dimensions, and that as these become a small fraction of a wavelength, the source becomes omnidirectional. By reciprocity, we may regard the absorber as behaving in a similar manner so that for absorbers very small compared with the wavelength, absorption takes place over 2π steradian, so increasing the effective area over that for a plane wave. Thus, if the single absorbers in Fig. 6 are regarded as the equivalent of a circular piston of the same area and the groups of three absorbers are considered in a like manner, the ratio of the directivities[9] of the single and grouped absorbers is 0·8:1 at 80 Hz, which is approximately the same as the ratio of most of the absorption coefficients obtained in practice. It should be noted that this concept applies rigorously only when the distances between absorbers are large compared with the dimensions of the absorbers, and that the module itself should be significantly smaller than a wavelength; otherwise phase effects will complicate the issue. For large areas or high frequencies, the area would 'radiate' a plane wave and this would be the deciding factor. It is difficult to see how, on any other basis, it is possible to obtain values of absorption coefficient as high as those measured for the narrow band bass absorbers.

This argument may well apply also in an inverse manner to the effect of the size of the room on the measurement of absorption in the bass. If the room is too small it follows that the diffusion is inadequate and the effective angle over which the module can absorb will be limited. This argument would seem to apply more to modules with a high absorption coefficient than those with a low one, and in view of the relatively low absorptive nature of the samples used in establishing the ISO standards, the possibility that this effect could extend for highly absorbing materials to frequencies well above 125 Hz may have been unnoticed.

3. Variation in mid-band absorption with relative area of measuring room

The percentage surface area covered by the modules in the three reverberation rooms for Figs. 7, 8, 9 and

10 was 6·3%, 4·4% and 2·0% for the rooms (KW, BPB, BRS) in ascending order of volume. On the other hand, the ratio of surface area of the modules to volume of the rooms is 8·5%, 4·5% and 1·1% respectively, and the percentage floor area covered by the modules was 25%, 27·5% and 11·5% respectively. The intermodule spacing was therefore slightly less in the case of the BPB room than at KW, and hence, the coupling must have been marginally greater, and may well have affected the results shown in Figs. 7 and 8 where the curve for the BPB room is close to that for the KW room over the frequency range 160 – 500 Hz. Otherwise, Figs. 7 to 10 confirm the results shown in Fig. 5. Thus, the BPB room compared to the KW room shows an increase in absorption coefficient over the 350 Hz to 2 kHz frequency range for the wide-band absorbers of 5% and the BRS room compared to the KW room an increase of 15%. If we now plot these three figures against the logarithm of the ratio of the total surface area of the reverberation room to the area of the absorbent sample in the room, we get a straight line shown in Fig. 13.

It is interesting to try and add to these points the data from Fig. 5 and Fig. 2. The curves from Fig. 2 are not directly applicable to Fig. 5 and must be corrected by an amount which can only roughly be estimated from Fig. 3 assuming a certain number of absorbers to be on the ceiling and the remainder to be on the walls. If these points are added to Fig. 13, it will be seen that they all form a straight line, showing very good correlation between the variables plotted.

Further data was obtained in the KW reverberation room by mounting additional modules on the walls, thus leaving the spacing of those on the floor the same as before. If an irregularity in the absorption and frequency curve around 400 Hz is ignored, an additional point could be plotted on Fig. 13 at co-ordinates (8·4, 89·5). Even if the irregularity is included, the co-ordinates obtained would be (8·4, 92·0) which is still in fairly good agreement with that predicted by extrapolation of the line in Fig. 13.

It may not be desirable to specify reverberation rooms larger than the ISO room for practical measurements of absorbers, but Fig. 13 at least enables a designer to estimate much more accurately from the absorption coefficient of absorbers measured in an ISO room when designing rooms of very different volume and hence surface area. The difference for large rooms is seen to be very appreciable especially under conditions where the reverberation time is

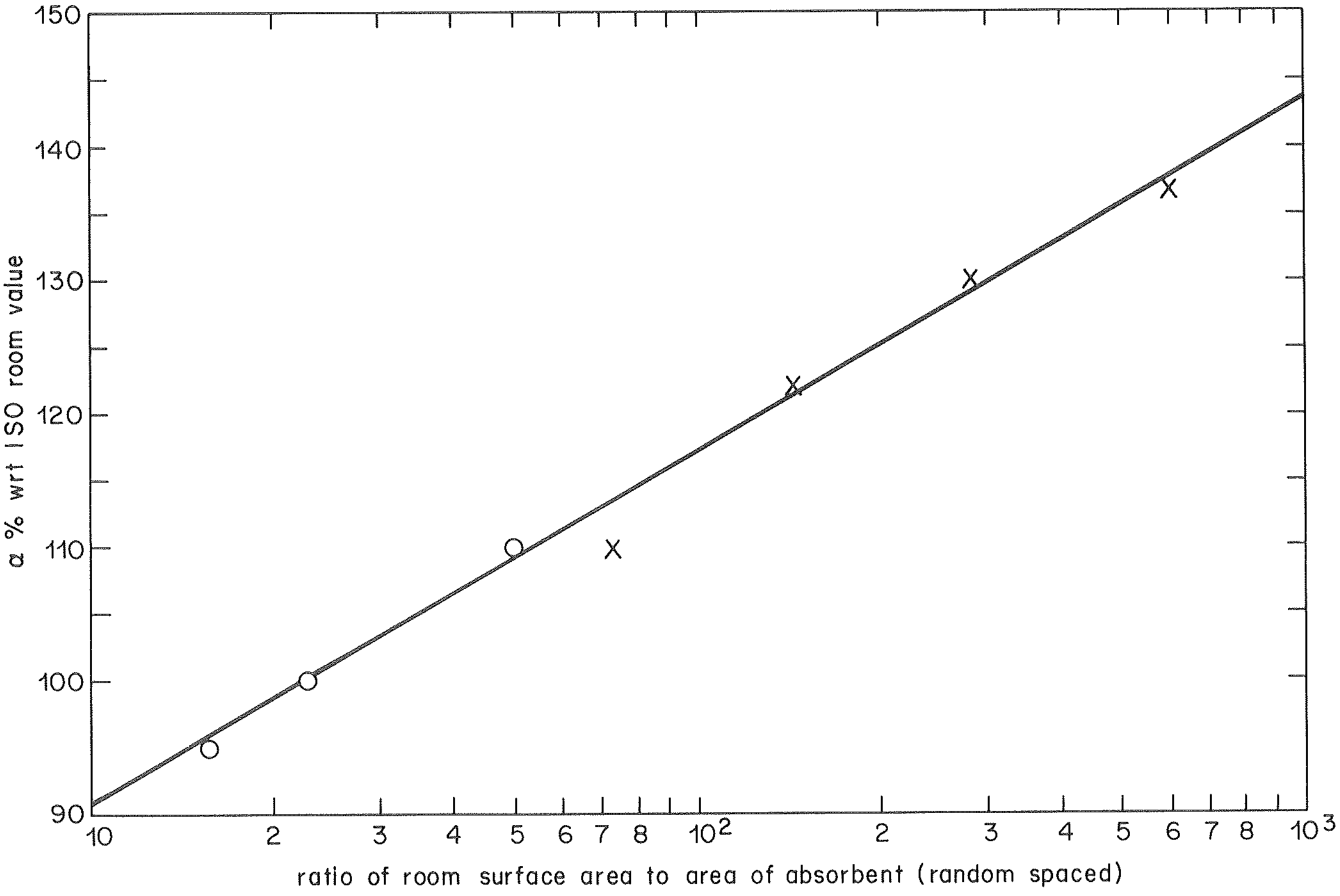


Fig. 13 - Relation between ratio of room surface area to area of absorbent and absorption coefficient for mid-band frequencies

O Reverberation room data – absorbers only on floor X Model Studio data – absorbers on five surfaces long.[1,2] In such cases the saving in cost in being able to specify the correct acoustic treatment could be considerable.

Extreme caution should, however, be exercised in attempting to apply the results given in Fig. 13 in all circumstances. Evidence already to hand suggests that other factors also affect the situation in contrary fashion. For example, many talks studios have been designed according to ISO absorption coefficients and have ended up overtreated. The ratio of surface area to treated area is, however, on average two to one in these cases, and thus according to Fig. 13 the studios should have been undertreated.

4. Conclusions

Measurements made in reverberation rooms of differing volume show that the absorption coefficient of a module cannot be regarded as a fixed quantity at a given frequency.

The absorption achieved is dependent to quite a large extent on the nature of the surroundings, and frequencies up to about 630 Hz may be involved for some effects and the whole frequency range for others. Thus, the absorption is affected by the volume of the room, the presence of local diffusing objects, by the number of absorbers in the room and their proximity, i.e. whether they are in groups or not and their area relative to that of the room.

Indications have been given of the order of magnitude of these effects so that some allowance can be made for them in the design of concert halls and large music studios, thus reducing the need for costly modifications later, the suggested allowances are, however, probably not applicable to small studios. It has also been concluded that present theories do not satisfactorily account for these effects and it is suggested that in one case the directivity may be a relevant factor.

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